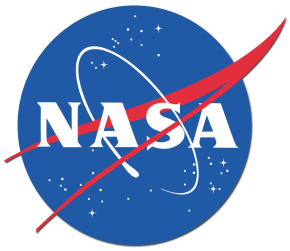

User Guide
NASA Unified WRF (NU-WRF)
Release 2-3.2.1
Document Revision: 1

Table of Contents

Overview

The Weather Research and Forecasting (WRF) model is a next-generation mesoscale weather forecast and assimilation system designed for portability, efficiency, and applications in both research and operations. WRF can be used for a wide range of configurations ranging from idealized large-eddy simulations to global modeling, with an emphasis on horizontal grid sizes in the range of 1–10 km. For large domain applications such as regional weather and climate processes, WRF is typically run within a domain covering several thousand kilometers using interactive nesting techniques with multiple grid refinements. See http://www.mmm.ucar.edu/wrf/users/docs/arw_v3.pdf for technical details on the official WRF system.

At NASA, WRF is being used to study a variety of phenomenon such as high impact weather and aerosol impacts. Several parameterizations of physical processes developed by NASA scientists have been implemented into WRF to better represent/simulate cloud-aerosol-precipitation-land surface processes. NASA Unified WRF (NU-WRF) combines these improvements in order to: (1) facilitate better use of WRF in scientific research; (2) reduce redundancy in major WRF development at NASA; (3) prolong the serviceable life span of WRF; and (4) allow better use of NASA high-resolution satellite data for research (short term climate and weather).

Enhancements

NU-WRF version 2-3.2.1 was released as beta software in March 2011. The version number "2-3.2.1" (or more simply, "release 2") designates the second official release of NU-WRF, which is based upon the WRF 3.2.1 code base. The NU-WRF software project consists of multiple software packages and enhancements built around the WRF modeling system, use cases with input data sets, and documentation describing the software and software processes.

Current Components

NU-WRF software consists of the following software components/enhancements:

- WRF and WRF/Chem 3.2.1 with additions:
    - Updated Goddard microphysics
    - Updated Goddard radiation (longwave and shortwave)
    - On-line coupling between GOCART aerosols and Goddard radiation
    - On-line coupling with the Land Information System (LIS)
    - Severe weather diagnostics (lightning flash rate, etc.)
- WPS 3.2.1 (Standard WRF pre-processors for terrain, land-use, and initial/lateral boundary conditions)

- WPP 3.2 (standard WRF post-processor/GRIB generator) with additions:
    - Severe weather diagnostics
- MET 3.0 (verification package)
- ARWpost 2.2 (WRF post-processor/GrADS and Vis5D file generator)
- RIP 4.6 (WRF post-processor/NCAR Graphics plotting software)
- SDSU
- Unified build system
- NASA data conversion utilities:
    - GEOS2WRF (for NASA GEOS-5 global model output)
    - MERRA2WRF (for NASA MERRA reanalysis output)
    - GOCART2WRF (for NASA GOCART global aerosol model output)
    - SST2WRF (for sea surface temperature analyses from Remote Sensing Systems)

Vendor-Specific Updates

The NU-WRF Release 2-3.2.1 NWP model is based on WRF 3.2.1, which was released by NCAR in August 2010. Upgrading to the 3.2.1 release adds additional features to NU-WRF, including (from http://www.mmm.ucar.edu/wrf/users):

- Bug fixes to various non-Goddard physics parameterizations
- New turbulence options
- Time-averaged flux output
- The WRF-Fire model
- Bug fixes and enhancements to the FDDA runtime options
- Vertical interpolation of relative humidity instead of specific humidity
- Fixes for digital filter initialization
- New 4D tracer array for chemistry and other applications
- New runtime option to skip variables from output files
- Bug fixes for nesting over complex terrain
- New option to increase vertical resolution by integer factor when nesting
- Improved domain decomposition for MPI and OpenMP

The WPS preprocessing software was upgraded to version 3.2.1. This software is used to process GRIB, GRIB2, and static terrestrial data for input to NU-WRF. Features introduced by WPS 3.2.1 (as documented at http://www.mmm.ucar.edu/wrf/users) include:

- Support for processing UK Met Office and NOGAPS fields
- Conversion of ECMWF snow depth to appropriate units
- Bug fix to processing ECMWF relative humidity
- Improved handling of missing relative humidity values in the upper atmosphere
- Upgrades to 2008 revisions of GRIB Table 3.2
- Several fixes to projection and interpolation options in metgrid
- Fixed interpolation of Gaussian grid data
- Added support for AFWA ice input

The WPP post-processing software was upgraded to version 3.2. This program allows conversion of NU-WRF netCDF output to GRIB format, along with calculation of a number of

diagnostic variables. WPP is a front-end to running the MET verification software on NU-WRF simulations. Changes introduced by WPP 3.2 (as documented at http://www.dtcenter.org/wrf-nmm/users) include:

- Bug fix to radar reflectivity computation using the Ferrier scheme
- Bug fix to interpolate 10-m winds from mass points to velocity points
- Bug fix to calculated dewpoint values
- Bug fix to calculated temperatures
- Enhancements to accommodate regular latitude/longitude projection

The MET verification software was upgraded to version 3.0. This software incorporates a number of verification measures appropriate for gridded and point-based data. Changes introduced by MET 3.0 (as documented at http://www.dtcenter.org/met/users) include:

- Support for verifying ensemble forecasts
- Multi-category contingency tables and skill scores
- Plotting of point observations
- Support for Air Force WWMCA cloud analysis
- Various bug fixes

The ARWpost post-processor was upgraded to version 2.2. This program allows conversion of NU-WRF netCDF output to GrADS format (and optionally Vis5d), along with calculation of a number of diagnostic variables. Changes introduced by ARWpost 2.2 (documented in the ARWpost README file) include:

- Fix for calculating relative humidity
- Using snow and graupel when calculating radar reflectivity
- Added latitude/longitude projection
- Added an extrapolation option

The RIP post-processing software was upgraded to version 4.6. This program allows for plotting of NU-WRF netCDF output using NCAR Graphics, along with calculation of a number of diagnostic variables. The only significant change was a bug fix to calculating geopotential height (personal correspondence from NCAR).

NU-WRF Group Improvements

Note: *The following documentation is also available from the "CHANGELOG.TXT" file in the NU-WRF source code.*

This release of NU-WRF adds a number of improvements to both the third-party software packages and in-house enhancements.

LIS was upgraded to version 6.0rp5. Changes introduced into this version include:

- GDAS and GFS T574 grib and writing GRIB output on a Mercator project
- LIS export data no longer overwrites the WRF data at water-points (for consistency)
- Checks for the surface physics scheme in wrfinput file is disabled,
- REAL (part of WRF) can now be built in a special mode to generate consistent initial conditions for coupled WRF-LIS runs.

Goddard radiation and GOCART are coupled when running with WRF/Chem. The radiative

transfer model now factors in aerosols, such as elemental carbon, sulfate, sea salt, and dust, in the short and long-wave radiation.

Severe weather diagnostics support was added to WPP for applicable physics schemes. These diagnostics include: maximum 10 meter wind speed, column mean vertical velocity, max column integrated graupel, maximum lightning threat, derived radar reflectivity, precipitation accumulation for a given time window, convective precipitation accumulation and others.

Utility enhancements include:

- MERRA2WRF now outputs relative humidity (RH) rather than specific humidity (QV). Also added improved error checking when calling the HDF4 library. Finally, a script for running the code on DISCOVER was fixed to gracefully handle bad PBS charge codes.
- GOCART2WRF includes a bug fix to calculate correct tendencies at the final time level, and adds error checking when calling the netCDF library.

Added a unified build system to compile all provided packages of NU-WRF. This build capability is currently targeted for NASA's NCCS Discover system, with environment settings (compilers, libraries, etc.) defined in a configuration file. See the README.TXT for usage details.

Using the Software

Acquiring the Source Code

Reference the *NU-WRF Source Code and Data* documentation at:
https://modelingguru.nasa.gov/docs/DOC-1834

Building the Source Code

The WRF modeling system is composed of a number of software packages, each of them with their own separate build system. To make it easier for the user to create desired executables and to more easily resolve dependencies between packages, the NU-WRF Release 2 includes a set of high-level "wrapper" scripts for building. With this new system, the user can build executables using a single script.

Basic Build on Discover

NU-WRF has a build mechanism that currently supports the NCCS Discover system. The most straightforward way to build the full system is to run the build script from the top-level folder:

```
./build.sh all
```

Or to build with chemistry enabled:

```
./build.sh allchem
```

This release also includes a special version of **real.exe** for use with coupled LIS initial conditions. Real ***must*** be built in a special mode for this purpose. Use the "lisreal" flag passed in the NU-WRF build script to enable the special build of real. For example:

```
./build.sh lisreal all
```

Excluding this flag will default to the standard version of real.

Selectively Building Packages

The build script will run a build on each package of NU-WRF. Because NU-WRF consists of multiple packages, this may take a while to finish. The user can selectively build packages by changing the "**all**" argument to one or more of the following: **wrf, chem, wps, wpp, rip, arwpost, geos2wrf, merra2wrf, gocart2wrf, sst2wrf, met**. For example to build the WRF model without chemistry along with WPS and WPP:

```
./build.sh wrf wps wpp
```

Note that this script makes some assumptions about how the user would like to configure the software. Many of these assumptions, including libraries, compiler/MPI modules and include files, are captured in a configuration file in the same directory as the build script: **discover.cfg**. While this script is not suitable for everyone and every environment, it can be a helpful place to start. The user may optionally create a new configuration file and override the default one like this:

```
./build.sh --config <config-file> all
```

About the Build System

The top-level build script calls lower-level build.sh wrapper scripts located in each package directory (WRFV3, WPS, etc.). Configuration settings are passed to the lower-level scripts via environment variables. Each lower-level script is customized to directly manage the appropriate build system (e.g., ./configure and ./compile for WRFV3, make for utils/geos2wrf), and to inject the appropriate configuration settings to the existing build system. For example, the build.sh for WPS will modify the configure.wps file generated by ./configure to update several library paths; the modified configure.wps is then used by the ./compile script.

One complication addressed by the build system is that several packages (WPS, WPPV3, and ARWpost) are dependent on libraries and object files from WRFV3. In addition, WPPV3 requires WRFV3 to be built in serial mode. To account for these dependencies, the build script has the following behavior:

- WRFV3 will always be built with MPI, except when WPPV3 needs to be built.
- If WPPV3 needs to be built, WRFV3 will first be built in serial mode, then WPPV3 will be built, and then WRFV3 will immediately be cleaned. This procedure will always occur before any other executables are built.

- If building WPS or ARWpost, the required WRFV3 files are first checked to see if they exist. If they are missing, WRFV3 will be compiled prior to WPS and/or ARWpost, regardless of whether 'wrf' is specified at the command line.

An additional complication is specific to NU-WRF: The coupling of LIS to WRF introduces several new library dependencies on WPPV3, including ESMF 3.1.0rp3. Furthermore, since WPPV3 expects WRFV3 to be compiled serially, the ESMF library must likewise be built in serial mode. To account for this, two separate ESMF libraries are specified in **discover.cfg**, one for each compilation mode. Also, the template configuration for WPPV3 is modified to add LIS-specific libraries so all necessary routines are resolved.

Currently, the build system is implemented for the Discover supercomputing cluster using Intel compilers. It may be desirable to add support for other computing systems (e.g., at NAS), so other configuration files could be written as well (e.g., pleiades.cfg). However, more significant changes would be required to specify alternative compilers or compiler flags and pass this information to the different packages.

Running NU-WRF

For a general guide to the WRF software, reference the *WRF on Discover* documentation at:
https://modelingguru.nasa.gov/docs/DOC-1671

For information on NU-WRF use cases, reference the *Running NU-WRF Use Cases* documentation at:
https://modelingguru.nasa.gov/docs/DOC-1883

Known Issues and Work-Arounds

The following issues/work-arounds are known in NU-WRF:

1. CFL errors. With the introduction of the WRF 3.2.1 code base at least one of the supported use cases produces CFL errors. This occurs with the official WRF 3.2.1 as well. This problem was reported to NCAR.
2. Namelist changes. In particular the "grid_fdda" setting has a new behavior introduced from WRF 3.2.1 which can cause errors.
3. Memory allocation errors. Certain cases (in particular case 9) can consume large amounts of memory. This behavior occurs in WRF as well.
4. Unreproducable results for different MPI decompositions. The current version of Goddard radiation may not produce the same results if the number MPI processes change. There is a planned fix for the next release of NU-WRF.
5. REAL (part of WRF) does not correctly process specific humidity (QV) from METGRID (part of WPS). A work-around was added to MERRA2WRF to output relative humidity instead. This behavior is also found in the official WRF.
6. First output dump missing. When using restart files, WRF will not produce the initial wrfout file. This behavior is also found in the official WRF.
7. LIS albedo not working for ensembles or tiles. This issue will be resolved in a subsequent release.